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(54) **A combine having a system estimator to monitor hydraulic system pressure.**

(57) A work vehicle, such as an agricultural combine (100), is provided with a controller (234, 236) that estimates a hydraulic pressure of a drive system based upon the speeds (304, 310) of the pump (110) (or engine) and motor (112) that drive apparatus, such as the threshing rotor (118). The pressure is estimated by calculating the ideal flow rates of both the pump (110) and the motor (112) based upon the sensed pump and motor speed signals (402, 404) and subtracting the ideal motor flow rate from the ideal pump flow rate. The controller (234, 236) may also generate a pump displacement control signal (412) in a conventional feedback control algorithm (408) and use that signal together with the sensed pump speed signal (402) for calculating the ideal pump flow rate.

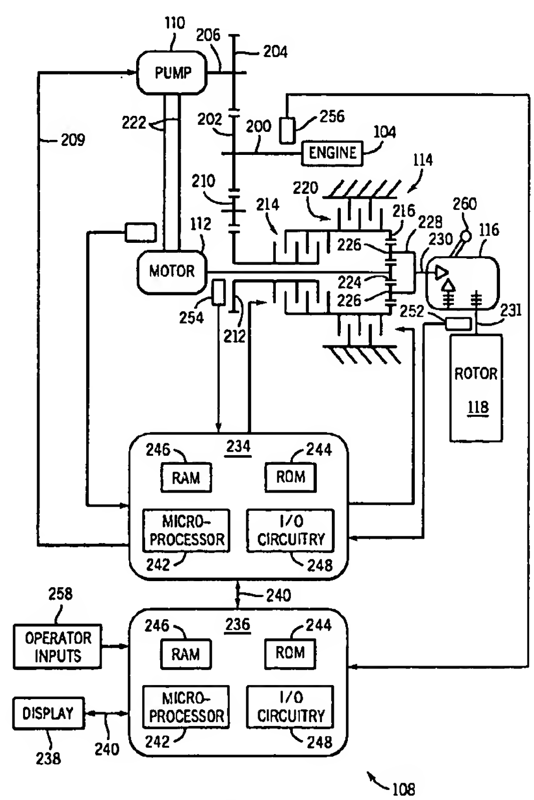

FIG. 2

EP 1 371 279 A1

Description

[0001] The invention relates to work vehicles, such as agricultural combines, and systems for controlling their operation. More particularly, it relates to control systems for obtaining the hydraulic system pressure of a drive system when dedicated transducers are not available.

[0002] Hydro-mechanical drive systems for crop processing and/or conveying apparatus, e.g. combine rotors, monitor a variety of system parameters when controlling the engagement, disengagement and speed of the apparatus. They typically have a variety of sensors that sense physical system parameters such as pressures, speeds, temperatures and positions of the various components comprising the systems.

[0003] Normally, physical system parameters, which are necessary for the feedback control algorithms and the display of data to the operator, are measured directly by using sensors. For example, a pressure sensor coupled to a hydraulic fluid conduit may directly indicate the hydraulic system pressure of the drive system. Other sensors may directly measure such parameters as rotor speed, shaft speed, oil temperature and the like.

[0004] Each sensor adds cost to the vehicle. Furthermore, it may be difficult if not impossible to measure certain parameters because of inaccessibility, sensor unreliability or the like. Because of these limitations it would be beneficial to eliminate one or more sensors to reduce the cost, reduce the size, and increase the reliability of the combine and its control systems.

[0005] One system parameter that may be estimated rather than sensed directly is hydraulic system pressure. Hydraulic system pressure is one of the indices used to determine if a rotor is starting to become slugged. The pressure can be sensed directly by a hydraulic fluid pressure sensor. Alternatively, and as disclosed in the present application, it can be estimated using a variety of other measured system parameters.

[0006] Once estimated, it can be used in a traditional control process such as delivering a warning to the operator that rotor slugging, engine stalling, or other mechanical damage is imminent.

[0007] Hydraulic system pressure is a particularly useful measure of rotor slugging (i.e. rotor jamming or plugging) in a combine that employs a PID feedback control loop to maintain the rotor speed constant, such as in the present system. In combines having such a control system, increasing loads on the motor experienced when the rotor begins to slug or jam, are not indicated by another parameter such as motor or rotor speed. When a PID control algorithm is used to keep the rotor operating at a constant speed, increased load on the rotor results in increased hydraulic fluid pressure to the hydraulic motor driving the rotor. This increased pressure produces more torque to keep the rotor operating at its constant selected speed. In short, as the load increases, the system compensates by applying increased hydraulic pressure to the motor to maintain the motor (and hence the rotor it drives) at a constant speed. It is hydraulic system pressure, not motor or rotor speed, that more accurately indicates incipient slugging of the rotor.

[0008] It is an object of this invention to provide a system that will estimate hydraulic system pressure without using a separate hydraulic pressure sensor.

[0009] It is a further object of this invention to provide a system that will predict rotor slugging and to indicate incipient slugging to the operator.

[0010] In accordance with the invention there is provided a work vehicle comprising a hydraulic drive system, said drive system comprising:

a hydraulic pump coupled to a prime mover for providing hydraulic fluid under pressure;
a hydraulic motor coupled by hydraulic circuitry to said hydraulic pump for receiving said hydraulic fluid under pressure;

characterised in that said vehicle further comprises an electronic control system for providing an estimation of the hydraulic pressure in said hydraulic circuitry, said control system comprising:

a pump speed sensor directed to a component connected to said pump for generating a signal indicative of the speed of said pump;
a motor speed sensor directed to a component connected to said motor for generating a signal indicative of the speed of said motor; and
at least one electronic controller coupled to said pump speed sensor and said motor speed sensor for receiving said pump speed signal and said motor speed signal, and configured to derive an estimation of the hydraulic pressure in said circuitry based upon said signals.

[0011] Such estimation provides the necessary information on the pressure in the circuitry and hence on the load of the apparatus connected to the drive system. No separate pressure sensor is required anymore and use can be made of speed sensors which are available for other routines, e.g. for feedback control of the various speeds.

[0012] The work vehicle may be constituted by an agricultural harvesting machine, e.g. a combine harvester, and the prime mover may comprise an internal combustion engine. Where there is a direct connection between the engine and the pump, the speed of the engine can be used as an indication for the speed of the pump.

[0013] Advantageously, the system may be used for estimating the load on a crop processing and/or conveying apparatus of the harvesting machine, e.g. the threshing rotor in a combine harvester or the feedrolls in a forage harvester. Such apparatus may be driven at various speeds via a multi-speed gearbox and/or a planetary gear arrangement. In the latter case, an input gear

may be coupled to the hydraulic motor and another input gear may be coupled to the engine.

[0014] When such variable transmission is provided between the engine and the apparatus, it may be advantageous to install a further speed sensor which is directed to a component connected to the processing and/or conveying apparatus in order to provide an apparatus speed signal to the electronic controller(s).

[0015] The electronic controller may be configured to estimate the pressure in the circuitry from the ideal flow rates which are calculated based upon the pump speed and motor speed signals. For instance, the controller may derive the pressure from the difference between the calculated flow rates.

[0016] Where a variable displacement pump is used, an electronic controller may vary the displacement of the pump through a displacement control signal, e.g. using a feedback control program. The control system may then combine the control signal and the pump speed signal in the routine used for the estimation of the pressure, e.g. for calculating the ideal pump flow rate.

[0017] Advantageously, the controller may compare the estimated pressure to a predetermined threshold value and generate a warning signal upon the estimation reaching or exceeding the predetermined value. The signal may be transmitted via a serial communication circuit to the controller of an electronic display for generating a warning to the operator.

[0018] An embodiment of the present invention will now be described in further detail, by way of example, with reference to the accompanying drawings wherein:

Figure 1 is a side schematic view of an agricultural combine having a hydraulic drive system with parameters estimated in accordance with the present invention;

Figure 2 is an electrical, hydraulic and mechanical schematic diagram of the drive system of the combine of Figure 1;

Figure 3 is a graphical representation of the pump and motor drive system model from which the hydraulic system pressure is estimated; and

Figure 4 is a top-level system diagram of the estimation and control functions performed by the electronic control system of the combine.

[0019] Referring to Figures 1 and 2, a work vehicle is illustrated, here shown as an agricultural combine 100. The work vehicle has a chassis 102 on which an engine 104 is mounted. A drive system 106 is coupled to and driven by engine 104 to rotate rotor 118. An electronic control system 108 is coupled to the engine and the drive system to monitor various sensors, to control the engine and to control the drive system.

[0020] The engine 104 is preferably an internal combustion engine, such as a multi-cylinder gasoline or diesel engine.

[0021] The drive system 106 includes a hydraulic pump 110 that is coupled to and driven by the engine, a hydraulic motor 112 that is fluidly coupled to and driven by pump 110, gear trains coupling engine 104 to the pump, engine 104 to a planetary gear arrangement, the planetary gear arrangement itself, and a gearbox driven by the planetary gear arrangement that, in turn, drives the combine rotor 118.

[0022] Rotor 118 rotates with respect to chassis 102 and threshes agricultural material, such as corn (maize) or wheat. A header 120 is coupled to the front of the combine chassis to gather the agricultural material from the field and direct it into the rotor. The agricultural material is gathered by the headers and cut. Once cut it falls into a header trough that includes an auger. The auger drives the agricultural material toward the mouth of the rotor via the feeder 124, which receives and feeds it to the threshing rotor 118.

[0023] A plurality of wheels 122 are coupled to the chassis to engage the ground and support the combine as it travels over the ground. One or more hydraulic motors (not shown) may be coupled to the wheels to drive the wheels in rotation, thereby driving the combine over the ground.

[0024] Figure 2 illustrates construction details of the work vehicle (and particularly the drive system) in a schematic form. Engine 104 has an output shaft 200 to which spur gear 202 is fixed. Gear 202 drives spur gear 204. Spur gear 204 is fixed to shaft 206, which is the input shaft to hydraulic pump 110.

[0025] Hydraulic pump 110 is a variable displacement pump in which the specific output can be varied under computer control. In particular, pump 110 has internal electronic actuators that vary the specific displacement of the pump in response to an electrical signal. Controller 234 applies the signal to pump 110 over electrical control lines 209.

[0026] Gear 202 also meshes with and drives spur gear 210, which is coupled to and drives the auger and header (not shown). Spur gear 210, in turn, meshes with and drives spur gear 212. Spur gear 212, in turn, is coupled to and drives the input shaft of engine-to-ring clutch 214.

[0027] Engine-to-ring clutch 214 is a hydraulically actuated multi-plate clutch that couples gear 212 (and hence engine 104) to ring gear 216 of planetary gear arrangement 114. When clutch 214 is engaged, engine 104 is coupled to and drives ring gear 216. When clutch 214 is disengaged, engine 104 is disconnected from ring gear 216.

[0028] A second clutch 220 (a ring-to-frame clutch) is coupled to and between ring gear 216 and the frame or chassis 102 (indicated by the ground symbol) to fix the ring gear with respect to the chassis or frame of the vehicle. When clutch 220 is engaged, ring gear 216 is fixed and cannot rotate.

[0029] Pump 110 is hydraulically connected to motor 112 by hydraulic conduits 222. These conduits conduct fluid to and from motor 112 to form a closed loop hydrau-

lic (hydrostatic) drive circuit.

[0030] Motor 112 is coupled to and drives sun gear 224 of planetary gear arrangement 114. Sun gear 224 drives planet gears 226, which drive planetary gear carrier 228.

[0031] Gearbox 116 is a multi-speed gearbox having three manually selectable gear ratios with an input shaft 230 and an output shaft coupled to rotor 118. It is shifted to alternatively select one of the three gear ratios by manual manipulation of gearshift lever 260.

[0032] Input shaft 230 of gearbox 116 is fixed to and rotates together with planetary gear carrier 228. The output shaft 231 of multi-speed gearbox 116 is coupled to and drives rotor 118.

[0033] It should be clear that power from engine 104 to rotor 118 follows two parallel paths. The first path is from engine 104, through the gearing, through clutch 214, through planet gears 226 and into shaft 230. The second parallel path is from engine 104, through pump 110, through motor 112, through sun gear 224, through the planet gear 226 and into shaft 230.

[0034] In a normal mode of operation, power through both paths is provided to the rotor. Engine 104 operates most efficiently at a set and predetermined rpm, yet the rotor cannot be operated at a set, predetermined speed, but must be variable over some range or ranges of speed to harvest the several types of crops it is intended and designed to do.

[0035] To provide this variable rotor speed, the parallel power path from engine 104 through pump 110 and motor 112 to the sun gear is provided. The planetary gear arrangement permits power through both paths to be applied to the rotor. The motor drives the sun gear, the engine drives the ring gear. The planetary gear carrier is coupled to and driven by both the sun and ring gears and applies that combined power to the rotor through gearbox 116.

ELECTRONICS

[0036] An electronic control system 108, including three digital controller circuits and their associated sensors, controls the operation of the foregoing machine elements.

[0037] The system 108 includes a first digital controller 234, a second digital controller 236 and a third digital controller 238 that are coupled together over a communications network, here shown as a CAN bus 240 in accordance with the SAE J1939 communications standard.

[0038] Each controller circuit 234, 236, and 238 are similarly constructed, and include a microprocessor 242, a read-only memory (ROM) 244, a random access memory (RAM) 246 and an input/output (I/O) circuit 248. The ROM includes a control program that controls the operation of the controller. The RAM is temporary storage space for numeric values used in computation, and the I/O circuit is configured to process and condition external communication signals including communications with the sensors and the other controllers on the CAN bus 240. Each of these circuits is connected using a data/address/control bus of standard design, which is not shown. The first digital controller 234 is connected to two speed sensors, a rotor speed sensor 252, and a motor speed sensor 254. These sensors are respectively coupled to rotor 118 and motor 112 to sense the rotational speeds of these devices and transmit a signal indicative of those speeds to the first digital controller 234.

[0039] The speed sensors in the present system preferably generate a series of pulses as the devices to which they are coupled rotate. The faster the engine, rotor and motor turn, the higher the frequency of the stream of pulses arriving at controllers 234 and 236 from the sensors.

[0040] Common sensor arrangements that generate such pulse sequences include Hall effect devices and inductive pickups that sense the passage of slotted disks or gear teeth mounted on the shafts of the engine, rotor and motor.

[0041] The first digital controller 234 is also connected to and controls three other devices: pump 110, engine-to-ring clutch 214 and ring-to-frame clutch 220. Controller 234 generates and transmits a signal indicative of a desired specific pump displacement to pump 110 over electrical signal lines 209. Pump 110 responsively changes its specific displacement to match the signal. In a similar fashion, controller 234 generates and transmits a clutch-engaging or clutch-disengaging signal to electrical solenoid valves (not shown) that conduct hydraulic fluid to and from the two clutches 214 and 220. The clutches responsively engage and disengage.

[0042] The I/O circuit of second digital controller 236 is connected to an engine speed sensor 256 and to operator input device 258. Engine speed sensor 256 generates a signal indicative of the engine speed, typically by generating a pulse train similar to the motor speed sensor. The operator input device 258 is preferably a switch responsive to operator manipulation that generates two separate signals, an "increase speed" signal and a "decrease speed" signal. Controller 236 is also connected to controller 234 and controller 238 via the CAN bus.

[0043] The third and final controller, controller 238, is a display controller. It is constructed the same as controller 234 and 236, but is dedicated to displaying data generated by the operator or the other controllers. This capability is provided by its own internal control program stored in its ROM memory. It includes a display device such as an LCD or electroluminescent display. It is coupled to the other controllers over CAN bus 240.

PROGRAMMING

[0044] Controllers 234, 236 and 238 include internal digital control programs that control their operation. These programs are stored in the ROM memory of each

controller. The programmed operation of each controller is discussed below.

[0045] During normal operation, controller 238 displays several data indicative of the vehicle's status. The first of these, the rotor speed, indicates the speed of the rotor. Controller 234 generates the rotor speed data from the rotor speed signal transmitted to controller 234 from rotor speed sensor 252. Controller 234 periodically calculates the rotor speed from the rotor speed signal and places this information on the CAN bus. The rotor speed is preferably calculated and placed on the CAN bus every 10 milliseconds.

[0046] Controller 238 is programmed to receive these rotor speed data over the CAN bus, and to translate them into display signals to drive its integral display. It applies the display signals to the display, thereby generating decimal digits on the display that represent the rotor speed. The display indicates the rotor speed as a sequence of decimal digits expressed in revolutions per minute.

[0047] Controller 238 also displays a range of rotor speeds the operator may select among. This range is displayed in the form of an upper and a lower limiting rotor speed. These limits are preferably generated by controller 234 and are transmitted every 10 to 200 milliseconds over the CAN bus to controller 238.

[0048] Controller 238 receives these speed range signals, translates them into display signals to drive its integral display, and applies the signals to the display thereby generating decimal digits on the display that represent the upper and lower rotor speed limit values. These values are preferably expressed in revolutions per minute.

[0049] Controller 236 receives an increase-rotor-speed signal and a decrease-rotor-speed signal (also known as operator speed requests or commands) from operator input device 258. These signals are generated by input device 258 when the operator manipulates device 238. Controller 236 transmits these operator requests on the CAN bus.

[0050] Controller 234 receives these operator requests and determines whether or not to change the speed of the rotor in response. If it decides that the rotor speed can be changed, it raises or lowers the commanded (e.g. the target) rotor speed accordingly.

[0051] Controller 234 controls the rotor speed by regulating the specific displacement of pump 110. Controller 234 is programmed to execute a conventional PID feedback control loop that uses the commanded rotor speed (from the operator input device), and the actual rotor speed (from the rotor speed sensor) as inputs to the PID control loop. The difference between these two speeds is the error signal that is minimised by the PID control loop.

[0052] Controller 234 changes the commanded rotor speed based on two things: first, a command by the operator using the operator input device to either raise or lower the current commanded speed, and second, controller 234's determination that the rotor can indeed be driven at the speed requested by the operator. If both conditions are met, controller 234 changes the commanded rotor speed and applies it as an input to the PID loop it executes.

[0053] Controller 234 also determines whether the motor or the engine (or both) drives the rotor by selectively engaging and disengaging the engine-to-ring clutch 214 and the ring-to-frame clutch 220. In the discussion below, controller 234 transmits engagement and disengagement signals to the hydraulic valve (not shown) that controls the engine-to-ring clutch, causing it to become engaged (thereby connecting the engine to the ring gear) and disengaged (breaking the engine-to-ring gear drive connection). Controller 234 also transmits engagement and disengagement signals to the hydraulic valve (not shown) that controls the ring-to-frame clutch, causing it to engage (locking the ring with respect to the chassis or frame) and disengage (releasing the ring to rotate with respect to the chassis or frame).

[0054] In the normal operating mode, both the motor and the engine drive the rotor. In this mode the engine runs at a relatively constant speed of 2150 rpm which, through the gearing and engine-to-ring clutch 214 connecting the engine to the ring gear, causes the ring gear to rotate at 2188 rpm.

[0055] The motor 112 is designed to be bi-directionally driven by pump 110 over a range of speeds from -4077 rpm to +3114 rpm. Given the gear ratios of the planetary gear arrangement, these speeds cause planetary gear carrier 228 to rotate at speeds ranging from 1144 to 2342 rpm.

[0056] In the normal or hydro-mechanical modes the rotor can be driven at an infinite number of speeds in either direction, the motor has a limited range of operating speeds, the engine operates at a relatively fixed speed, and gearbox 116 has a predetermined set of gear ratios. By "gear ratio" we means the ratio of gearbox input shaft speed versus gearbox output shaft speed. Given these constraints, for any selected gear ratio of gearbox 116, there is an associated and predetermined range of permissible rotor speeds. These speeds are expressed as a rotor speed upper limit and a rotor speed lower limit. Again, each of the selectable gear ratios of gearbox 116 has an associated and different rotor speed upper and lower limit.

[0057] The input shaft 230 of gearbox 116 is connected to and driven by the planetary gear carrier 228. The gearbox has three different selectable gear ratios -- ratios of gearbox input shaft to output shaft speeds. These gear ratios are selectable by manual operator manipulation of a conventional gearshift lever 260.

[0058] Given the gear ratio of the planetary gear arrangement and a ring gear speed of 2188 rpm, input shaft 230 of gearbox 116 rotates at speeds of between 1144 and 2342 rpm; at 1144 rpm, the motor is rotating at -4077 rpm. At 2342 rpm, the motor is rotating at 3114 rpm.

[0059] When the input shaft 230 rotates at a speed of between 1144 and 2342 rpm, he highest gearbox gear ratio rotates the output shaft of the gearbox (and the rotor to which it is coupled) at a respective speed of between 589 and 1206 rpm. For the middle gear ratio, this respective speed is between 391 and 800 rpm. For the lowest gear ratio, this respective speed is between 222 and 454 rpm. The output shaft speed varies with the motor speed.

[0060] When the motor rotates at -4077 rpm (and, again, assuming an engine speed of 2150 rpm), the rotor rotates at 589, 391, or 222 rpm, depending upon the gearbox 116 gear ratio. When the motor rotates at +3114 rpm, the rotor rotates at 1206, 800, or 454 rpm, depending upon the gear ratio.

[0061] Controller 234 achieves intermediate speeds within each of these three rotor speed ranges by varying the motor speed from -4077 to +3114 rpm. Controller 234 does this by controlling the specific displacement of pump 110 in the PID feedback control loop.

[0062] The operator is interested in controlling the rotor speed, since the rotor speed determines the rate at which the combine performs its work. It is for this reason that controller 234 is configured to transmit the rotor speed on the CAN bus to controller 238 to be displayed.

[0063] The operator can select any rotor speed, but the ranges of permissible rotor speeds are limited, as mentioned above. Each gearbox gear ratio has its own associated range of rotor speeds. As a result, the operator is also interested in knowing the range of rotor speeds that he can select. It is for this reason that controller 234 transmits the upper and lower rotor speed limits (which depend upon the currently selected gearbox gear ratio) on the CAN bus to controller 238 to be displayed.

[0064] Due to the PID feedback control of rotor speed, as the engine and rotor are loaded more and more, controller 234 and the engine governor compensate by keeping the engine, the motor and the rotor running at a constant speeds for a given commanded rotor speed. The only significant indication that the rotor is being loaded more heavily is the pressure in the hydraulic lines coupling the pump 110 to the motor 112. As controller 234 and the engine compensate for the increased load, the pressure in the hydraulic lines connecting the pump 110 and the motor 112 generally increases proportionately.

[0065] This additional pressure, in turn, causes the motor to apply a greater torque to the rotor through the drive system sufficient to counteract the increased load and keep the rotor turning at the commanded speed.

[0066] If the load on the rotor continues increasing, eventually pump 110 reaches a maximum pressure above which it cannot go without stalling the engine 104. The rotor becomes "slugged". "Slugging" as used herein refers to the condition in which the system is loaded so highly that the engine and/or the motor are unable to maintain the rotor at the commanded speed.

[0067] The operator receives little or no indication that the rotor is slugged. Since the system effectively maintains the rotor at the proper speed right up to the point at which it is slugged, there is only a small change in rotor speed to indicate incipient slugging.

[0068] For this reason the system 108 estimates hydraulic system pressure (in the preferred embodiment, the pressure difference across the lines 222 that conduct hydraulic fluid to and from the motor) and uses that pressure to indicate to the operator that the rotor is slugged or that slugging is about to occur.

[0069] By providing such notice, the operator can take preventive action, such as slowing the vehicle down and reducing the rotor speed. When the vehicle is slowed down, agricultural matter such as the crop being harvested is propelled into the rotor area at a reduced rate, which reduces the load on the rotor drive system. Furthermore, the power consumed in driving the vehicle over the ground is also reduced.

[0070] To estimate the hydraulic system pressure, controller 234 includes a mathematical model of the rotor drive system that relates engine speed, motor speed, and the specific displacement of the pump to the differential pressure in the hydraulic conduits. The specific displacement of the pump is a function of the signal that controller 234 applies to pump 110 to change its specific displacement.

[0071] By applying the motor speed signal, the engine speed signal, and the pump signal generated by the PID feedback control loop of controller 234 to the mathematical model of the drive system, controller 234 can estimate the hydraulic system pressure and determine whether slugging is occurring or is about to occur. If so, controller 234 sends a signal indicative of slugging to controller 238, which displays a corresponding slugging message on its integral display.

DYNAMIC SYSTEM MODEL

[0072] Controller 234 incorporates several equations, which may be expressed, stored and calculated in a variety of forms well known in the art, to estimate the hydraulic system pressure in the conduits coupling pump 110 and motor 112. These equations constitute the mathematical model of the system and are provided below.

1. Pump model:

[0073]

$$\text{Pump\_Vel} = \text{K1}*\text{Eng\_Vel} \qquad \text{Eqn. 1}$$

$$\text{Pump\_Disp} = \text{Pump\_I}*\text{K2} \qquad \text{Eqn. 2}$$

Q2-1 = Pump_Disp*Pump_Vel Eqn. 3

where "Pump_Vel" is pump speed or velocity, "Eng_Vel" is engine speed or velocity, "Q2-1" is the ideal flow rate of the pump for fluid leaving the pump (i.e. the pressurised fluid), "Pump Disp" is the pump displacement, "Pump_I" is pump current (i.e. the magnitude of the current signal applied to the pump by controller 234 to set the specific displacement of the pump), "K1" is a constant (the engine-to-pump gear ratio), and "K2" is a constant (the pump displacement-to-pump current signal gain).

2. Motor model:

[0074]

Q1-2 = Motor_Disp*Motor_Vel Eqn. 4

where "Q1-2" is the ideal flow rate of fluid through the motor back to the pump (i.e. the low pressure fluid returned to the pump), "Motor Disp" is the specific fluid displacement of the motor, and "Motor Vel" is the motor speed velocity.

3. Hydraulic circuit model:

[0075]

P1-2 = K3*(Q2-1- Q1-2) Eqn. 5

where P1-2 is the hydraulic system pressure difference between the hydraulic conduits, and K3 is a constant (the effective orifice constant). These equations are combined to provide the model 300 shown in Figure 3.

[0076] Referring to Figure 3, block 302 illustrates the pump model. Using the engine speed ("Engine Vel") 304 and the pump current ("Pump_I") 306 (i.e. the signal applied to the pump by controller 234) controller 234 solves for Q2-1, the ideal flow out of pump 110.

[0077] Block 308 illustrates the model of the hydraulic motor 112. Using the motor velocity ("Motor_Vel") 310 provided by the motor speed sensor and the constant specific displacement ("Motor_Disp") of the motor, controller 234 solves for the ideal flow through the motor ("Q1-2").

[0078] Block 312 illustrates the model of the hydraulic circuits (i.e. the hydraulic lines) connecting the pump and motor. Using the flow out of the motor ("Q1-2") and the ideal flow out of the pump and into the motor ("Q2-1"), controller 234 solves for the hydraulic system pressure ("P1-2") 314.

[0079] Once controller 234 estimates the system pressure based on engine speed, motor speed and the specific displacement signal that controller 234 applies to the pump, controller 234 compares this estimated system pressure with a predetermined value of the system pressure that is stored in the ROM memory of controller 234.

[0080] If the estimated pressure meets or exceeds the predetermined pressure, controller 234 sends a message to controller 238 over the CAN bus indicating that the threshold (or predetermined) pressure has been exceeded. Controller 238 receives this signal and generates a display signal that is transmitted to the integral display of controller 238. This display signal causes display 238 to display the message "SLUGGING" on the display.

[0081] It should be clear that, in determining slugging, controller 234 estimates a physical parameter (hydraulic system pressure) of the rotor drive system based upon an internal mathematical model of the drive system and other measured physical parameters (the motor speed and the engine speed). In the PID feedback control loop, controller 234 determines the appropriate specific displacement (e.g. drive) signal to be applied to the pump to maintain the rotor speed constant. Controller 234 combines this pump drive signal with the motor speed and the engine speed to estimate the system pressure.

[0082] This process is shown schematically in Figure 4, which graphically represents the estimation and feedback control processes.

[0083] On the left hand side of Figure 4, the engine speed 402 and the motor speed 404 are received by controller 234 as inputs from the engine and motor speed sensors. These inputs are provided to both a system estimating portion 406 of the control program of controller 234 and to a conventional control algorithm portion 408 of the control program of controller 234.

[0084] The system estimating portion 406 estimates the hydraulic system pressure 410 based upon the engine speed, the motor speed and the pump command signal (e.g. the current applied to the pump to vary its specific displacement) 412 - which is proportional to the specific displacement of pump 110.

[0085] The pump command signal 412 is calculated by the conventional control algorithm portion of the control program of controller 234 when the conventional control portion (which includes the PID feedback control loop) calculates the pump command signal that will maintain the rotor at a constant speed. It is provided to the system estimating portion 406 as shown by line 414.

[0086] Thus, a conventional control program 408 generates one of the values 412 that is used by the system estimating portion 406 to estimate a system parameter 410. The generated value 412 is produced by the PID feedback control loop of the conventional control program 408 as a controlled variable of the control loop - in this instance the current (i.e. specific displacement) signal driving the pump. The estimated system parameter 410 is produced by the system estimating portion 406 and is used as a reference by the conventional control program 408 for slug detection and operator notifi-

cation.

[0087] It will be obvious to those skilled in the art that various changes may be made without departing from the scope of the invention as defined by the claims.

Claims

1. A work vehicle (100) comprising a hydraulic drive system, said drive system comprising:

   a hydraulic pump (110) coupled to a prime mover (104) for providing hydraulic fluid under pressure;
   a hydraulic motor (112) coupled by hydraulic circuitry (222) to said hydraulic pump (110) for receiving said hydraulic fluid under pressure;

   characterised in that said vehicle (100) further comprises an electronic control system (108) for providing an estimation (314) of the hydraulic pressure in said hydraulic circuitry (222), said control system comprising:

   a pump speed sensor (256) directed to a component (104) connected to said pump (110) for generating a signal (402) indicative of the speed (304) of said pump;
   a motor speed sensor (254) directed to a component connected to said motor (112) for generating a signal (404) indicative of the speed (310) of said motor; and
   at least one electronic controller (234, 236) coupled to said pump speed sensor (256) and to said motor speed sensor (254) for receiving said pump speed signal (402) and said motor speed signal (404), and configured to derive an estimation (410) of the hydraulic pressure in said circuitry (222) based upon said signals (402, 404).

2. A work vehicle according to claim 1, **characterised in that** said at least one electronic controller (234, 236) is configured to derive said estimation (410) from calculations of the ideal flow rates of said pump (110) and said motor (112), based upon said pump and motor speed signals (402, 404).

3. A work vehicle according to claim 2, **characterised in that** said at least one electronic controller (234, 236) is configured to derive said estimation (410) from the difference between said calculated pump and motor flow rates.

4. A work vehicle according to any of the preceding claims, **characterised in that:**

   said pump is a variable displacement pump (110) coupled to said at least one electronic controller (234, 236) for receiving therefrom a displacement control signal (412) for varying the displacement of said pump; and
   said at least one electronic controller (234, 236) is configured to combine said pump speed signal (402), said motor speed signal (404) and said displacement control signal (412) for the derivation of said pressure estimation (410).

5. A work vehicle according to claim 4, **characterised in that** said at least one electronic controller (234, 236) includes a feedback control program (408) that generates said displacement control signal (412).

6. A work vehicle according to claim 4 or 5, when appended to claim 2 or 3, **characterised in that** at least one said electronic controller (234, 236) is configured to calculate the ideal flow rate of said pump (110), based upon said pump speed signal (402) and said displacement control signal (412).

7. A work vehicle according to any of the preceding claims, **characterised in that:**

   said at least one electronic controller (234, 236) comprises a first electronic controller (234) that is coupled to said motor speed sensor (254) and a second electronic controller (236) that is coupled to said pump speed sensor (256); and
   said electronic control system (108) further comprises a communication circuit (240) configured to couple said first and second electronic controllers (234, 236).

8. A work vehicle according to claim 7, **characterised in that**:

   said second electronic controller (236) is configured to transmit a signal (402) indicative of said pump speed (304) to said first electronic controller (234); and
   said first electronic controller (234) is configured to derive said estimation (410) of the hydraulic pressure in said circuitry (222) based upon said speed signals (402, 404).

9. A work vehicle according to claim 7 or 8, **characterised in that** said communication circuit is a serial communication circuit, such as a CAN bus (240).

10. A work vehicle according to any of the claims 7 to 9, when appended to claims to 5 or 6, **characterised in that** said first electronic controller (234) is configured to generate said displacement control signal (412).

11. A work vehicle according to any of the preceding

claims, **characterised in that** said at least one electronic controller (234, 236) is configured to compare said estimated hydraulic pressure (410) to a predetermined value and to generate a warning signal upon said estimated pressure (410) meeting or exceeding said predetermined value.

12. A work vehicle according to claim 11, **characterised in that** said electronic control system (108) further comprises a display coupled to an electronic display controller (238), and a communication circuit (240) configured to couple said display controller (238) and said at least one electronic controller (234, 236), said display controller being configured to generate a warning message on said display upon receipt of said warning signal.

13. A work vehicle according to any of the preceding claims, **characterised in that** said vehicle is an agricultural harvesting machine (100) and said prime mover comprises an internal combustion engine (104).

14. A work vehicle according to claim 13, **characterised in that** said pump speed sensor (256) is directed to said engine (104) for generating an engine speed signal (402).

15. A work vehicle according to claim 13 or 14, **characterised in that** said hydraulic motor (112) is coupled to the drive of a crop processing and/or conveying apparatus (118).

16. A work vehicle according to claim 15, **characterised in that** said drive comprises a planetary gear arrangement (114) comprising a gear (216) disposed for coupling to said engine and a gear (224) coupled to said hydraulic motor (112).

17. A work vehicle according to claim 15 or 16, **characterised in that** said drive comprises a multi-speed gearbox (116) having a plurality of selectable gear ratios.

18. A work vehicle according to any of the claims 15 to 17, **characterised in that** said electronic control system (108) comprises a further speed sensor (252) coupled to said at least one electronic controller (234, 236) and directed to a component connected to said crop processing and/or conveying apparatus (118) for generating a signal indicative of the speed of said apparatus.

19. A work vehicle according to according to any of the claims 15 to 18, **characterised in that** work vehicle is a combine harvester (100) and said crop processing and/or conveying apparatus comprises a threshing rotor (118).

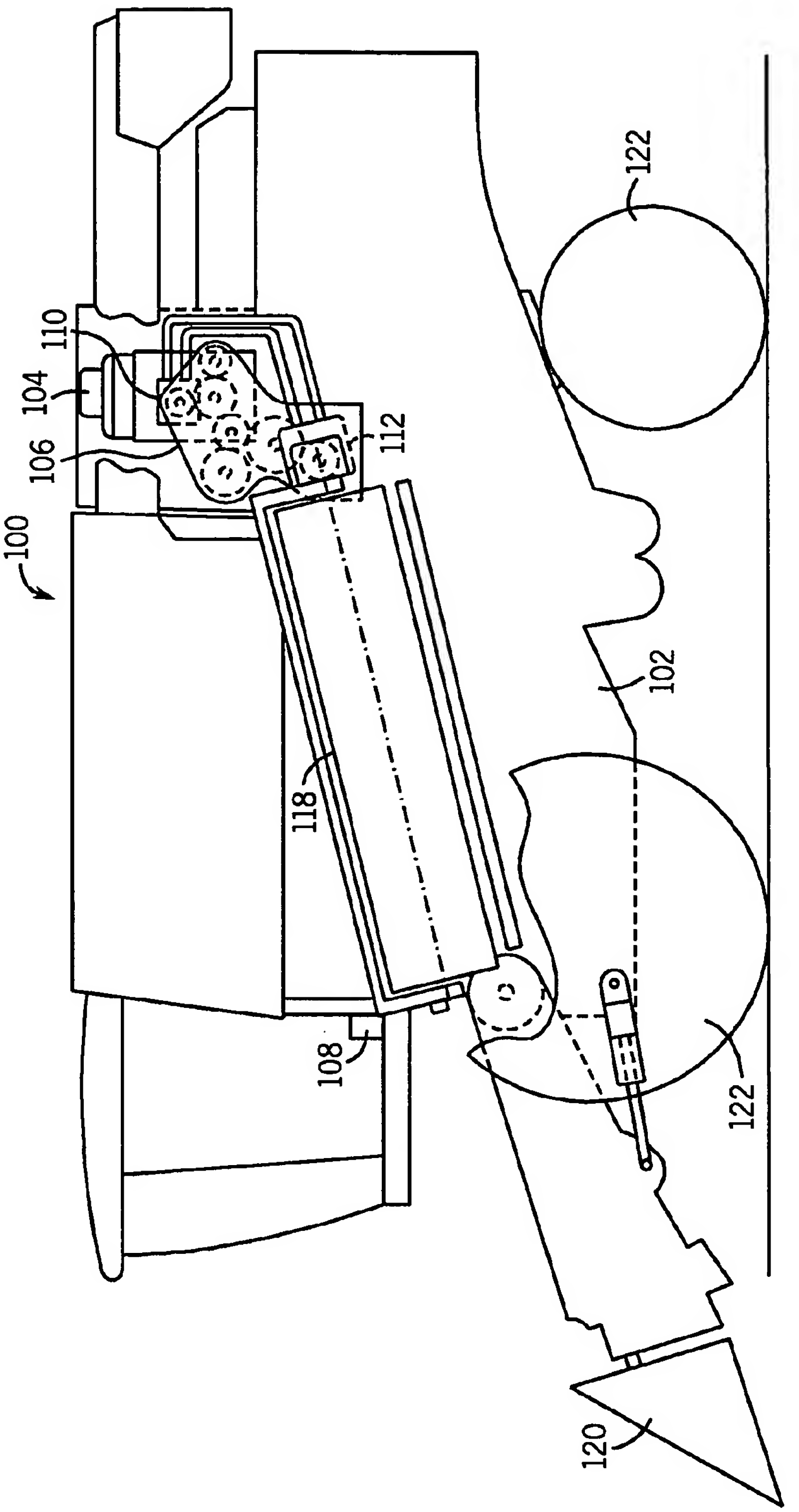

FIG. 1

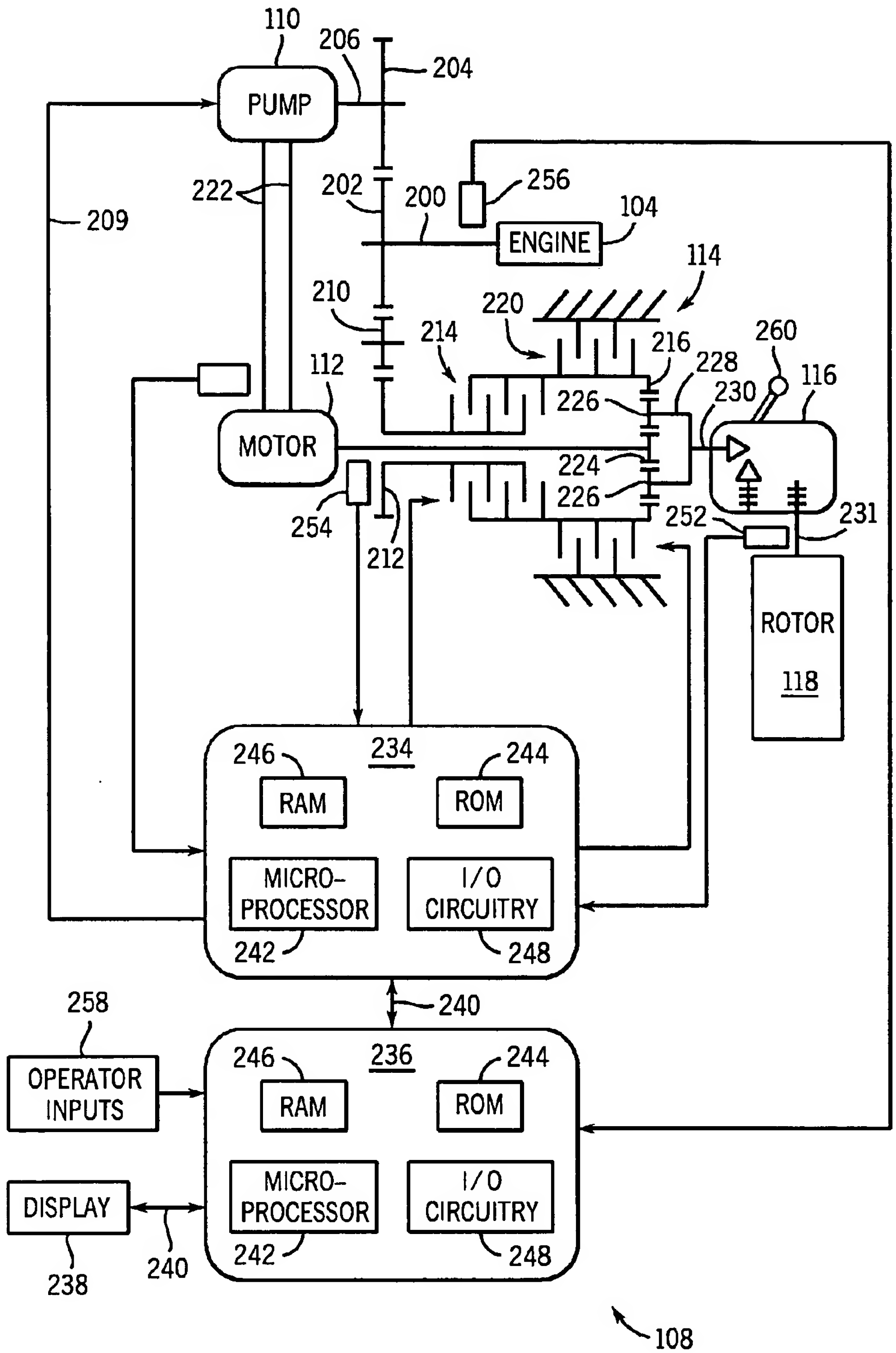
110
206
204
PUMP
222
202
200
256
104
209
ENGINE
114
210
220
214
216
260
112
228
116
230
226
MOTOR
224
226
254
252
231
212
ROTOR
118
246
234
244
RAM
ROM
MICRO-
PROCESSOR
I/O
CIRCUITRY
242
248
240
258
246
236
244
OPERATOR
INPUTS
RAM
ROM
MICRO-
PROCESSOR
I/O
CIRCUITRY
DISPLAY
238
240
242
248
108

FIG. 2

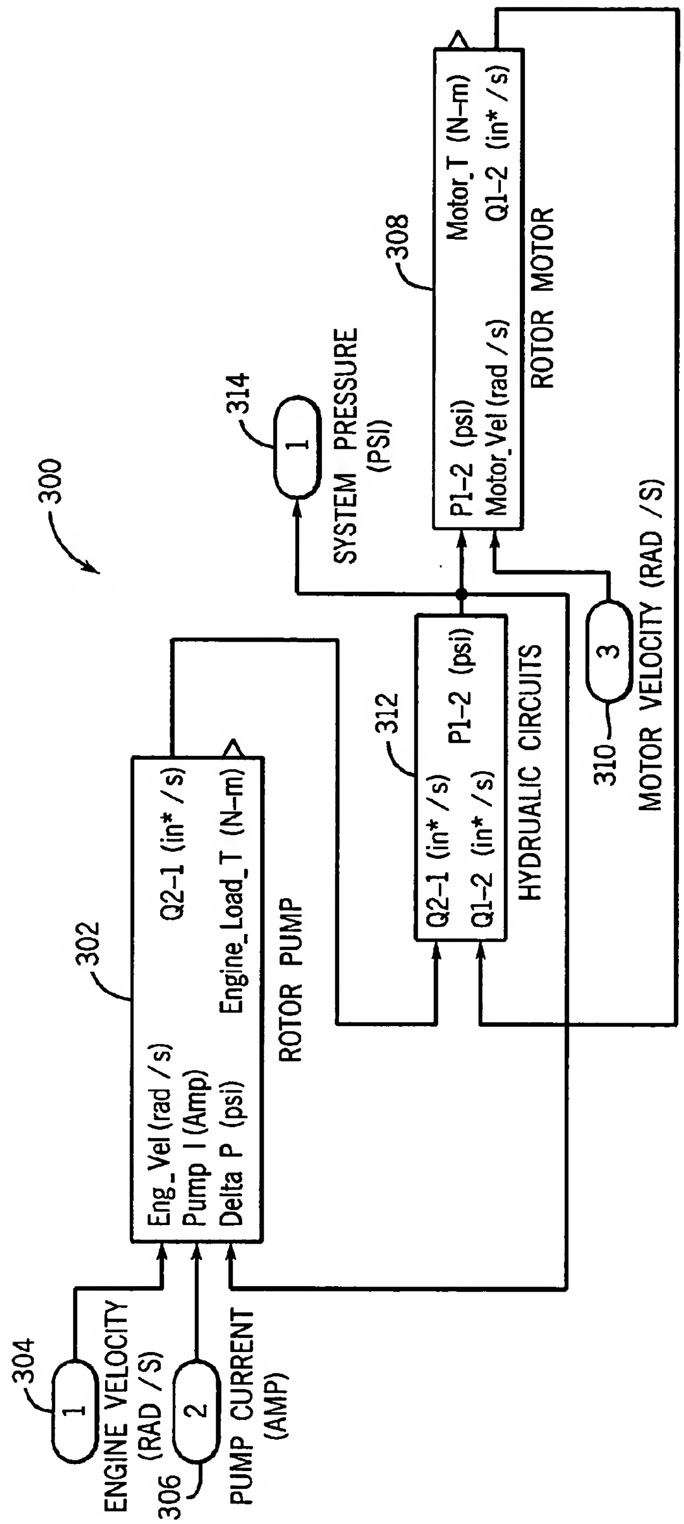
300
302
Eng._Vel (rad /s)
Pump I (Amp)
Delta P (psi)
Q2-1 (in* /s)
Engine_Load_T (N-m)
ROTOR PUMP
304
1
ENGINE VELOCITY
(RAD /S)
306
2
PUMP CURRENT
(AMP)
312
Q2-1 (in* /s)
Q1-2 (in* /s)
P1-2 (psi)
HYDRUALIC CIRCUITS
314
1
SYSTEM PRESSURE
(PSI)
308
P1-2 (psi)
Motor_Vel (rad /s)
Motor_T (N-m)
Q1-2 (in* /s)
ROTOR MOTOR
310
3
MOTOR VELOCITY (RAD /S)

FIG. 3

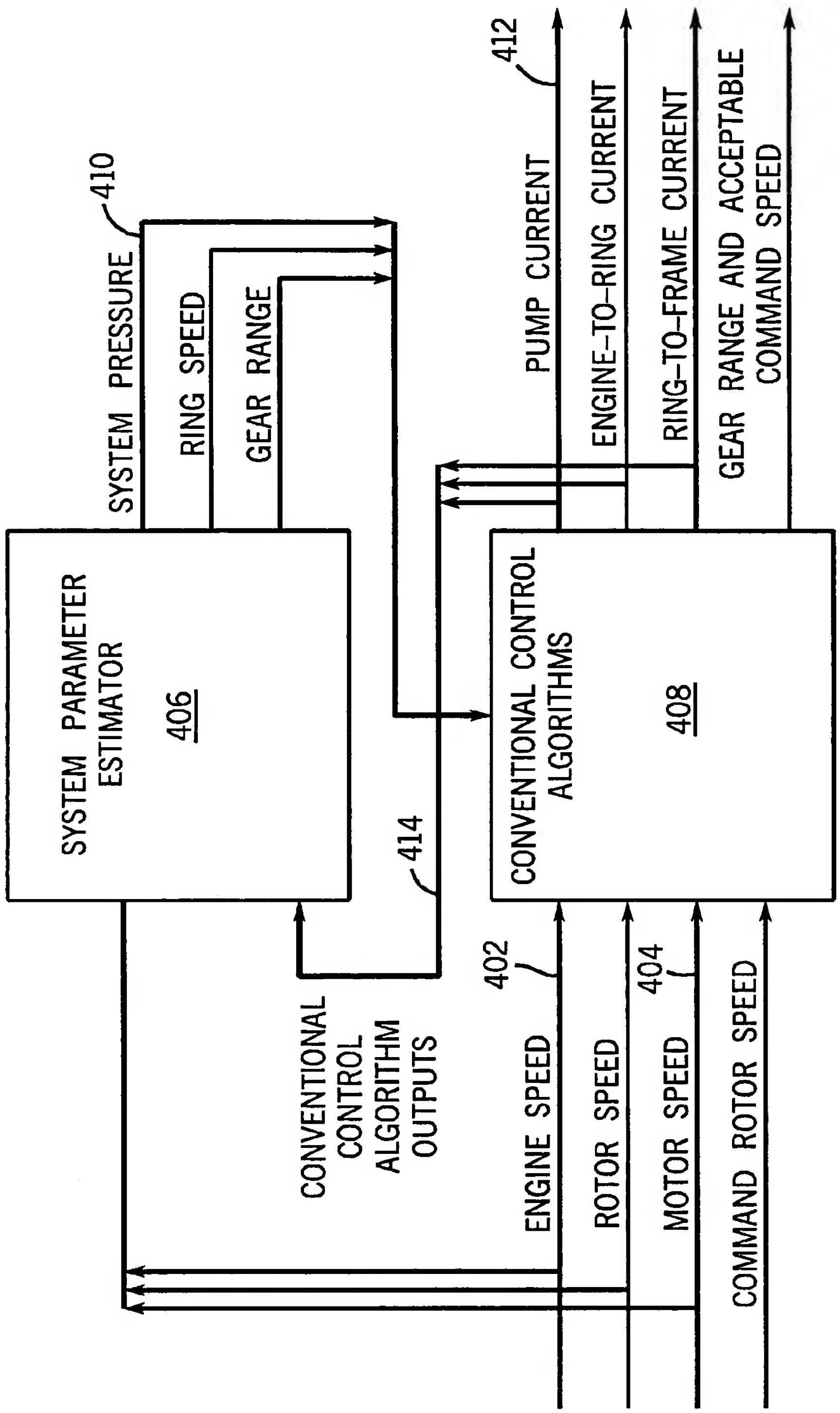
SYSTEM PARAMETER ESTIMATOR
406
CONVENTIONAL CONTROL ALGORITHMS
408
SYSTEM PRESSURE
RING SPEED
GEAR RANGE
410
412
PUMP CURRENT
ENGINE-TO-RING CURRENT
RING-TO-FRAME CURRENT
GEAR RANGE AND ACCEPTABLE COMMAND SPEED
414
CONVENTIONAL CONTROL ALGORITHM OUTPUTS
402
404
ENGINE SPEED
ROTOR SPEED
MOTOR SPEED
COMMAND ROTOR SPEED

FIG. 4

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 10 1669

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X	DE 198 58 673 A (SAUER SUNDSTRAND GMBH & CO) 6 July 2000 (2000-07-06) * column 1, line 56 - column 5, line 5; figure 2 * * column 2, line 14 - line 24 *	1-3,6-9, 12,18,19	A01D41/127 F16H61/46
X	* column 5, line 2 - line 5 * * column 2, line 14 - line 24 *	4	
X	* column 2, line 33 - line 37 *	5	
X	* column 2, line 33 - line 37 *	10	
Y		11,13-17	

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Y	US 5 107 722 A (NIKOLAUS HEINRICH W ET AL) 28 April 1992 (1992-04-28) * column 1, line 5 - line 11 * * column 3, line 50 - line 53; figure 1 * -----	13-17	
			TECHNICAL FIELDS SEARCHED (Int.Cl.7)
			F16H A01D

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27 August 2003	Bordeaux, J

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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D : document cited in the application
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EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 03 10 1669

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The members are as contained in the European Patent Office EDP file on
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27-08-2003

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